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**NEW, CONTINUATION, DIVISIONAL OR  
CONTINUATION-IN-PART APPLICATION  
UNDER 37 C.F.R. §1.53(b)**

Attorney Docket No. 6206-000003

Express Mail Label No. EL684104729US

Date October 25, 2000

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

Hon. Commissioner of Patents and Trademarks  
Washington, D. C. 20231



Sir:

Transmitted herewith for filing under 37 C.F.R §1.53(b) is a patent application for DIGITAL SIGNAL PROCESSING FOR SYMMETRICAL STEREOPHONIC IMAGING IN AUTOMOBILES

identified by: ☐ First named inventor \_\_\_\_\_  
or ☒ Attorney Docket No. (see above)

**1. Type of Application**

☒ This application is a new (non-continuing) application.

☐ This application is a ☐ continuation / ☐ divisional / ☐ continuation-in-part of prior application No. \_\_\_\_\_. Amend the specification by inserting before the first line the sentence:

--This is a [continuation/division/continuation-in-part] of United States patent application No. \_\_\_\_, filed \_\_\_\_.--

☐ The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied, is considered part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

If for some reason applicant has not requested a sufficient extension of time in the parent application, and/or has not paid a sufficient fee for any necessary response in the parent application and/or for the extension of time necessary to prevent the abandonment of the parent application prior to the filing of this application, please consider this as a Request for an Extension for the required time period and/or authorization to charge our Deposit Account No. 08-0750 for any fee that may be due. THIS FORM IS BEING FILED IN TRIPLICATE: one copy for this application; one copy for use in connection with the Deposit Account (if applicable); and one copy for the above-mentioned parent application (if any extension of time is necessary).

**2. Contents of Application**

a. Specification of 14 pages;

- ☐ A microfiche computer program (Appendix);  
☐ A nucleotide and/or amino acid sequence submission;

☐ Because the enclosed application is in a non-English language, a verified English translation ☐ is enclosed ☐ will be filed.

☐ Cancel original claims \_\_\_\_ of the prior application before calculating the filing fee. (At least one original independent claim must be retained for filing date purposes.)

b. ☒ Drawings on 5 sheets (16 Figures);



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- c. ☒ A signed Oath/Declaration ☐ is enclosed / ☒ will be filed in accordance with 37 C.F.R. §1.53(f).

The enclosed Oath/Declaration is ☒ unexecuted / ☐ a copy from a prior application under 37 C.F.R. §1.63(d) / ☐ accompanied by a statement requesting the deletion of person(s) not inventors in the continuing application.

d. **Fees**

FILING FEE	Number	Number	Basic Fee
CALCULATION	Filed	Extra	Rate
			\$710.00
Total Claims	4 - 20 =	0 ×	\$18.00 = 0.00
Independent Claims	1 - 3 =	0 ×	\$80.00 = 0.00
Multiple Dependent Claim(s) Used .....			\$270.00 = 0.00
FILING FEE - NON-SMALL ENTITY .....			710.00
FILING FEE - SMALL ENTITY: Reduction by 1/2 .....			
<input type="checkbox"/> Verified Statement under 37 C.F.R. §1.27 is enclosed.			
<input type="checkbox"/> Verified Statement filed in prior application.			
Assignment Recordal Fee (\$40.00) .....			
37 C.F.R. §1.17(k) Fee (non-English application).....			
<b>TOTAL</b> .....			<b>710.00</b>

- ☒ A check is enclosed to cover the calculated fees. The Commissioner is hereby authorized to charge any additional fees that may be required, or credit any overpayment, to Deposit Account No. 08-0750. A duplicate copy of this document is enclosed.

- ☐ The calculated fees will be paid within the time allotted for completion of the filing requirements.
- ☐ The calculated fees are to be charged to Deposit Account No. 08-0750. The Commissioner is hereby authorized to charge any additional fees that may be required, or credit any overpayment, to said Deposit Account. A duplicate copy of this document is enclosed.

3. **Priority Information**

- ☐ **Foreign Priority:** Priority based on \_\_\_\_\_ Application No. \_\_\_\_\_, filed \_\_\_\_\_, is claimed.
- ☐ A copy of the above referenced priority document ☐ is enclosed / ☐ will be filed in due course, pursuant to 35 U.S.C. §119(a)-(d).



Attorney Docket No. 6206-000003

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- ☒ **Provisional Application Priority:** Priority based on United States Provisional Application Serial No. 60/179,254 filed January 31, 2000; United States Provisional Application Serial No. 60/163,221 filed November 2, 1999; United States Provisional Application Serial No. 60/162,044 filed October 26, 1999, United States Provision Application Serial No. 60/161,276 filed October 25, 1999; are claimed under 35 U.S.C. §119(e).

4. **Other Submissions**

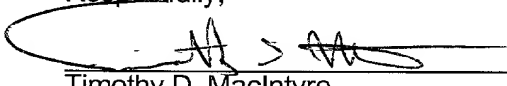
- ☐ A Preliminary Amendment is enclosed.
- ☐ An Information Disclosure Statement, \_\_\_\_\_ sheets of PTO Form 1449, and \_\_\_\_\_ patent(s)/publications/documents are enclosed.
- ☐ A power of attorney
- ☐ is submitted ☐ with the new Oath/Declaration.
- ☐ is of record in the prior application and ☐ is in the original papers / ☐ a copy is enclosed.
- ☐ An Assignment of the invention
- ☐ is enclosed with a cover sheet pursuant to 37 C.F.R. §§3.11, 3.28 and 3.31.
- ☐ is of record in a prior application. The assignment is to \_\_\_\_\_, and is recorded at Reel \_\_\_\_\_, Frame(s) \_\_\_\_\_.
- ☐ An Establishment of Assignee's Right To Prosecute Application Under 37 C.F.R. §3.73(b), and Power Of Attorney is enclosed.
- ☒ An Express Mailing Certificate is enclosed.
- ☒ Other: Acknowledgement Postcard \_\_\_\_\_

Attention is directed to the fact that the correspondence address for this application is:

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Respectfully,

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# DIGITAL SIGNAL PROCESSING FOR SYMMETRICAL STEREOPHONIC IMAGING IN AUTOMOBILES

## FIELD OF THE INVENTION

The present invention relates generally to stereophonic sound reproduction in automobiles and, more particularly, to a digital signal processing technique that provides optimum image localization and spatial enhancement symmetrically at the left and right  
5 sides of an automotive listening environment.

## BACKGROUND OF THE INVENTION

An acoustic characteristic common to most automotive sound systems is a rapid rate-of-change of the interaural phase difference (IPD) to a maximum of substantially 180 degrees, at substantially 200 Hz, occurring at both the left and right sides of the automotive listening environment. This IPD anomaly typically occupies a narrow  
10 "transition region" (e.g., 100 Hertz wide) and occurs in opposite polarities at the left and right sides of the listening environment. Additionally, this IPD anomaly may be characterized as an abrupt, non-linear phase shift as opposed to a linear phase shift or time delay function.

15 Therefore, it is desirable to provide a digital signal processing technique for symmetrical stereophonic image enhancement in an automotive listening environment. In particular, the technique introduces a rapid rate-of-change of phase shift between the signal channels, to a maximum of substantially 180 degrees, at substantially 200 Hertz. As a result, there exists two 180 degree phase shifts: one occurring naturally in the  
20 automotive listening environment and the other provided by the above-described digital signal processing technique. The two phase shifts occur within the narrow transition region, thereby correcting IPD to substantially zero above and below the frequency of the transition region. Since the transition region typically occupies less than 16% of the phase sensitive frequencies between 150 and 800 Hz, the effect of the non-corrected  
25 IPD in the transition region is generally not audible. In this way, the present invention provides theoretically optimal symmetrical IPD compensation for an automotive listening environment.



## DISCUSSION OF RELATED KNOWN ART

Although each having inherent performance limitations, various analog and digital signal processes have been employed to improve stereophonic imaging in automobiles. For instance, the use of a digital or analog time delay circuit in one stereo channel has been widely practiced and provides improved image localization at the side of an automobile corresponding to the channel in which the delay is applied. This approach provides neither optimal nor symmetrical image enhancement. Moreover, this approach actually degrades image localization at the non-corrected side of the automobile.

U.S. Patent No. 4,817,162 by Kihara describes a second-order analog phase shifter at substantially 200 Hertz in one channel and a second-order analog phase shifter at substantially 600 Hertz in the remaining channel, each of which provide 360 degrees of phase shift. The displaced frequency 360-degree phase shift functions operating in separate channels differentially interact in such a manner as to provide substantially 180-degrees of phase shift between the channels for frequencies between substantially 200 and 600 Hertz. The Kihara process is inherently limited, however, in terms of the rate-of-change of phase between the channels because the Q factor of the 360-degree phase shifters must be restricted in order to provide 180-degrees of differential phase shift over the desired 200 to 600 Hertz bandwidth. For this reason, the Kihara process does not provide optimum compensation of IPD in an automotive listening environment.

U.S. Patent No. 5,400,405 by Petroff teaches analog circuitry comprising frequency-selective polarity inversion through analog filter summing and asymmetrical cross coupling to compensate for the closer proximity of one speaker at a selected listening location. A three-position switching system allows user selection of optimum image enhancement at one of three listening locations. The circuit provides asymmetrical rather than symmetrical image localization enhancement in an automobile.

U.S. Patent No. 6,038,323 by Petroff describes summed analog low-pass and high-pass filters, each having cut-off frequencies at substantially 200 Hz, which are added in-phase and constitute a filter network having a 360-degree phase shift. Such filter network operates in one channel and a first order phase analog shifter providing a 180-degree phase shift operates in the remaining stereo channel, thereby providing a substantially 180-degree differential phase shift between the stereo channels for frequencies above substantially 200 Hz. Although the resulting rate-of-change of phase



shift between the channels is superior to that provided by prior art image enhancement processes, it is nevertheless not adequately rapid to enable fully optimized symmetrical correction of IPD in an automobile. Implementation of such circuit through digital signal processing is possible, but presents significant complications and limitations that may be circumvented through alternative digital processes. Specifically, the 360-degree phase shift function in one channel and the 180-degree phase shift function in the remaining channel may be more efficiently and effectively replaced by a digital signal process that more directly provides a rapid rate-of-change phase shift to a maximum of 180-degrees in one channel.

### OBJECTS OF THE INVENTION

It is an object of the present invention to describe an image enhancement digital signal process in which optimum stereophonic localization is provided symmetrically at the left and right sides of an automobile.

It is another object of the present invention to describe an image enhancement digital signal process that introduces a rapid rate-of-change of phase shift between the channels, to a maximum of substantially 180-degrees, at substantially 200 Hz.

It is yet another object of the present invention to describe a constant time delay, equal to the fixed delay introduced by the above digital signal process, applied to the non-processed channel to eliminate a delay differential between the channels.

It is still another object of the present invention to describe a spatial enhancement signal process, through the application of equalized and attenuated stereo difference signals prior to the image enhancement signal process, which may be implemented by means of digital signal processing or analog circuitry.

### SUMMARY OF THE INVENTION

The present invention is a digital signal processing technique in which optimum stereo localization is provided symmetrically at the left and right sides of an automotive listening environment. The processing technique introduces a rapid rate-of-change of phase shift between the channels, to a maximum of substantially 180-degrees, at substantially 200 Hz. In addition, a constant time delay, equal to the time delay introduced by the above-described processing technique, is applied to the remaining channel. The constant time delay substantially eliminates a fixed delay differential that



would otherwise exist between the channels. It is envisioned that the clock frequency of the digital signal process may be adjusted in order to precisely set the frequency at which the rapid rate-of-change of phase shift occurs. In an additional feature of the present invention, equalized and attenuated stereo difference signals may be applied prior to the above-described processing technique, thereby providing spatial enhancement of the reproduced sound.

### BRIEF DESCRIPTION OF THE DRAWINGS

The objects and advantages of the present invention will be more fully understood from the following description taken with the accompanying drawings in which:

Figures 1 and 2 are graphs depicting the uncorrected IPD as measured at the left side and the right side, respectively, of a typical automotive listening environment;

Figure 3 is a graph depicting the compensating phase shift function, applied to the left channel, as provided by the digital signal processing technique of the present invention;

Figures 4 and 5 are graphs depicting the corrected IPD resulting from the application of the digital signal processing technique of the present invention, as measured at the left side and the right side, respectively, of an automotive listening environment;

Figure 6 is a graph that compares the approximate phase shift function of a first prior art image enhancement circuit to the compensating phase shift function of the present invention;

Figure 7 is a graph that compares the approximate phase shift function of a second prior art image enhancement circuit to the compensating phase shift function of the present invention;

Figure 8 is a graph that compares the approximate phase shift functions of a third and fourth prior art image enhancement circuits to the compensating phase shift function of the present invention;

Figure 9 is a block diagram of a first preferred embodiment of a digital signal processing system in accordance with the present invention;

Figure 10 is a block diagram of a first alternative embodiment of the compensating phase shift component of the present invention;



Figures 11 and 12 are block diagrams of a second and third alternative embodiment, respectively, of the compensating phase shift component of the present invention;

Figures 13 and 14 are block diagrams of a fourth and fifth alternative embodiment, respectively, of the compensating phase shift component of the present invention; and

Figures 15 and 16 are block diagrams of a sixth and seventh alternative embodiment, respectively, of the compensating phase shift component of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An acoustic characteristic common to most automotive sound systems is a rapid rate-of-change of the interaural phase difference (IPD) occurring at both the left and right sides of the automotive listening environment. Figures 1 and 2 illustrate the uncorrected interaural phase difference (IPD) as measured at the left side and right side, respectively, of a typical automotive listening environment. In each figure, IPD is defined as the left ear phase relative to the right ear phase as a function of frequency. Typically, this IPD anomaly occupies a narrow "transition region" (e.g., 100 Hertz wide) and occurs in opposite polarities at the left and right sides of the listening environment.

In accordance with the present invention, a digital signal processing technique is provided for symmetrical stereophonic image enhancement in an automotive listening environment. In particular, the technique introduces a rapid rate-of-change of phase shift between the signal channels, to a maximum of substantially 180 degrees, at substantially 200 Hertz. The compensating phase shift function A as implemented by the digital signal processing technique of the present invention is illustrated in Figure 3.

For purposes of this discussion, the phase shift functions are expressed in terms of the left channel phase in relation to the right channel phase. Although the compensating phase shift function is preferably applied to the left channel or driver's side of the automotive sound system, this phase shift function could also be applied to the right channel of the automotive sound system while still providing symmetrical stereophonic image enhancement as perceived at both sides of the listening environment.

As a result, there exists two 180 degree phase shifts: one occurring naturally in the automotive listening environment and the other provided by the above-described



digital signal processing technique. The two phase shifts occur within the narrow transition region, thereby correcting IPD to substantially zero above and below the frequency of the transition region as shown in Figures 4 and 5. In addition, since the transition region typically occupies less than 16% of the phase sensitive frequencies between 150 and 800 Hz, the effect of the non-corrected IPD in the transition region is generally not audible. In this way, the present invention provides theoretically optimal symmetrical IPD compensation for an automotive listening environment.

Figures 6-8 contrast the compensating phase shift function of the present invention with the approximate phase shift functions as produced by four known prior art approaches. Figure 6 is a graph that compares the approximate phase shift function B, as produced by an image enhancement circuit employing a time delay in one channel, to the compensating phase shift function A of the present invention. Figure 7 is a graph that compares the approximate phase shift function C, as produced by the image enhancement circuit as described in U.S. Patent No. 4,817,162, to the compensating phase shift function A of the present invention. Figure 8 is a graph that compare the approximate phase shift functions D and E as produced by the image enhancement circuits as described in U.S. Patent Nos. 5,400,405 and 6,038,323, respectively, to the compensating phase shift function A of the present invention. Each of the phase shift functions from the prior art have been approximated to the best of the applicant's understanding.

A preferred embodiment of a digital signal processing system in accordance with the present invention is depicted in Figure 9. The digital signal processing system generally includes an optional spatial enhancement component 12, a compensating phase shift component 14 and an optional subwoofer component 16. As will be more fully explained below, the compensating phase shift component 14 embodies the principles of the present invention. While the following description is provided with reference to an audio sound system in an automotive environment, it is readily understood that the broader aspects of the present invention may also be applicable to other listening environments where the listener is asymmetrically positioned between the speakers of the audio system.

The spatial enhancement component 12 receives an input stereo signal having a left channel input signal  $L_{in}$  and a right channel input signal  $R_{in}$ . The left channel input signal  $L_{in}$  is applied to subtractor a which in turn derives an L-R stereo difference



signal. The output of subtractor a is applied to stepped low-pass filter b having a step attenuation function at a low/mid frequency. The output of low-pass filter b is then applied to attenuator c which provides an attenuation function equal to -xdB (typically  $0 < x < 10$ ). The output of attenuator c and the left channel input signal  $L_{in}$  are applied to summer d. Summer d provides as output a spatially enhanced left channel signal  $L'$ .

Likewise, the right channel input signal  $R_{in}$  is applied to subtractor e which in turn derives an R-L stereo difference signal. The output of subtractor e is applied to stepped low-pass filter f having a step attenuation function at a low/mid frequency. The output of low pass filter f is applied to attenuator g which provides an attenuation function equal to -xdB (typically  $0 < x < 10$ ). The output of attentuator g and right channel input signal  $R_{in}$  are applied to summer h, where summer h provides as output a spatially enhanced right channel signal  $R'$ . As will be apparent to one skilled in the art, subtractors a and b may cross-connect L-R and R-L difference signals, respectively.

In the above manner, an L-R difference signal is applied to a shelved low-pass filter at a low/midrange frequency, attenuated and mixed with the left input signal. Similarly, an R-L difference signal is applied to a shelved low-pass filter at a low/midrange frequency, attenuated and mixed with the right input signal. As a result, the spatial enhancement component 16 serves to compensate for the absence of long time delay reflected fields commonly found in an automotive listening environment, thereby improving the spatial quality of the reproduced sound. One skilled in the art will readily recognize that the spatial enhancement component may be implemented by either analog or digital circuitry.

In the preferred embodiment, the spatially enhanced left channel signal  $L'$  serves as an input to a phase shift subcomponent i. In accordance with the present invention, phase shift subcomponent i introduces a rapid rate-of-change of phase to a maximum of substantially 180-degrees at substantially 200 Hz, thereby producing an output image enhanced left channel signal  $L_{out}$  for driving a left channel amplifier and/or left side speaker(s) of an audio sound system.

An adjustable clock 18 may optionally serve as an input to phase shift subcomponent i. It is envisioned that the clock frequency may dictate the frequency at which the phase shift subcomponent i introduces the rapid rate-of-change. In this way, the frequency at which the rapid rate-of-change occurs may be precisely set to



coincide with the naturally occurring phase shift of the particular automotive listening environment.

Concurrently, a time delay is introduced into the spatially enhanced right channel signal  $R'$  by a time delay subcomponent  $j$ . The time delay is equal to the fixed time delay component introduced in the left channel by the digital signal process  $i$ . As will be apparent to one skilled in the art, the fixed time delay component is caused by the presence of the digital circuitry as opposed to the processing performed by the digital circuitry. The output image enhanced right channel signal  $R_{out}$  is then used to drive a right channel amplifier and/or right side speaker(s) of the audio sound system. Thus, the present invention provides a rapid rate-of-change of phase between the stereo channels to a maximum of 180-degrees at substantially 200 Hz. This results in optimum symmetrical IPD compensation and a corresponding enhancement of stereophonic localization on both sides of an automobile listening environment. One skilled in the art will readily recognize that subcomponents  $i$  and  $j$  may be interposed to opposite channels without effecting the general concepts and performance characteristics of the present invention.

A subwoofer component 16 may be used for driving an optional subwoofer (not shown). A sample of left channel output signal  $L_{out}$  and a sample of right channel output signal  $R_{out}$  may serve as the inputs to the subwoofer component 16. These input signals are combined by summer  $k$  which provides as output a subwoofer signal  $S_{out}$ . Thus, the subwoofer signal  $S_{out}$  inherently exhibits constant phase characteristics above and below the narrow transition region. Additionally, the subwoofer signal  $S_{out}$  inherently exhibits an extremely rapid cut-off low pass filter function below substantially 200 Hertz by virtue of the above-described phase inversion characteristics between the input signals above 200 Hertz. Such characteristics of the subwoofer signal  $S_{out}$  are ideal for driving a subwoofer used to augment a conventional stereophonic sound system. This approach also eliminates the need for employing a high order low pass filter in derivation of the subwoofer signal. Again, the subwoofer component 16 may be implemented by analog or digital circuitry.

An alternative embodiment for the compensating phase shift component 14 is shown in Figure 10. In this embodiment, the left channel input signal  $L_{in}$  is received into a filter bank  $l$ . Filter bank  $l$  may include low-pass, narrow band-pass, and high-pass filter functions. The output from the low-pass function is applied zero degrees of phase shift



at throughput  $m$ . The output from the band-pass function is applied to a 90-degree phase shift process  $n$  which may include an equivalent time delay at such filter's center frequency. The output from the high-pass function  $l$  is applied to a 180-degree phase shift process  $o$  which includes a phase inverter. These outputs are then each applied to summer  $p$  which provides as output an image enhanced left channel signal  $L_{out}$ . As previously described, the right channel input signal  $R_{in}$  is applied to time delay  $q$ . Time delay  $q$  introduces a constant time delay equal to the fixed delay introduced into the left channel by the above-described digital signal processing. Time delay  $q$  provides as output an image enhanced right channel signal  $R_{out}$ .

Thus, the outputs of a non-inverting high-order low-pass filter, a 90-degree phase shifted narrow band-pass filter, and an inverting high-order high-pass filter are summed and applied to one channel. The inclusion of the 90-degree phase shifted narrow band-pass filter serves to preclude a cancellation effect in the frequency region between the low-pass and high-pass filters, since a 90-degree phase shifted signal sums properly with either a non-inverted (0-degree phase shift) or an inverted (180-degree phase shift) signal. Thus, a notch in the output response does not occur. Frequencies below, within, and above the narrow band-pass filter exhibit substantially 0-degree, 90-degree, and 180-degree phase shifts, respectively. In this way, a rapid rate-of-change of phase shift to a maximum of 180-degrees occurs about the narrow band-pass filter at substantially 200 Hz.

A second alternative embodiment for the compensating phase shift component 14 is shown in Figure 11. The left channel input signal  $L_{in}$  is received into a filter bank  $a'$ . In this case, filter bank  $a'$  includes a low-pass filter function and a high-pass filter function. The low-pass output of filter bank  $a'$  is applied 0-degrees of phase shift at throughput  $b'$ . The high-pass output of filter bank  $a'$  is applied to a 180-degree phase shift process  $c'$  which includes a phase inverter. These outputs are then each applied to a summer  $d'$  which provides as output an image enhanced left channel signal  $L_{out}$ . The right channel input signal  $R_{in}$  is applied to time delay  $e'$ . Time delay  $e'$  introduces a constant time delay equal to the fixed delay introduced in the left channel and thereby provides as output an image enhanced right channel signal  $R_{out}$ .

In this approach, the narrow band-pass filter is eliminated and the cut-off frequencies of the non-inverting low-pass and inverting high-pass filters are substantially the same or narrowly separated. It is preferable to define the parameters of the low-



pass and high-pass digital filters in such a way as to skew the phase in the stop-band relative to the phase in the pass-band of each such filter. The skewed phase stop-bands complicate the associated digital processing, but are necessary to avoid a phase cancellation that would otherwise occur in the overlap region between the opposing phase low-pass and high-pass filters.

A third alternative embodiment for the compensating phase shift component 14 is shown in Figure 12. In this instance, the left channel input signal  $L_{in}$  is applied to time delay function  $f'$ . Time delay function  $f'$  introduces time delay  $T$  that varies inversely as a function of frequency  $F$  above 200 Hz and remains constant below 200 Hertz. In this manner, the time delay function  $f'$  may be aligned to provide a rapid rate-of-change in phase to a maximum of 180-degrees at substantially 200 Hertz. Thus, the time delay function  $f'$  provides as output an image enhanced left channel signal  $L_{out}$ . The right channel input signal  $R_{in}$  is applied to time delay  $g'$ . Time delay  $g'$  introduces a constant time delay equal to the fixed delay introduced in the left channel below substantially 200 Hz and thereby provides as output image an enhanced right channel signal  $R_{out}$ . Thus, the time delay function varies inversely with frequency above substantially 200 Hz and is equivalent to the inverting high-pass filter. Alternatively, such time delay may vary as a function of all audio frequencies, most significantly, however, for frequencies above substantially 200 Hz.

Figure 13 depicts a fourth alternative embodiment for the compensating phase shift component of the present invention. In this case, the left channel input signal  $L_{in}$  is applied to a digital high-Q all-pass filter  $h'$  which provides a rapid rate-of-change of phase shift to a maximum of substantially 180-degrees. High-Q all-pass filter  $h'$  provides as output an image enhanced left channel signal  $L_{out}$ . More specifically, the Q factor for filter  $h'$  is greater than one and preferably greater than three. As will be apparent to one skilled in the art, the phase shift function of the high-Q all-pass filter  $h'$ , in which maximum phase shift is limited to 180-degrees, may not ordinarily be implemented through an analog phase shifter or all-pass circuit. The right channel input signal  $R_{in}$  is applied to a time delay  $i'$ . Time delay  $i'$  introduces a constant time delay equal to the fixed delay introduced in the left channel and thereby provides as output an image enhanced right channel signal  $R_{out}$ . Thus, the high-Q all-pass filter is equivalent to the summed low-pass and high-pass filters, and it introduces a rapid rate-



of-change of phase shift to a maximum of substantially 180-degrees at substantially 200 Hz.

Figure 14 depicts a fifth alternative embodiment for the compensating phase shift component of the present invention. The left channel input signal  $L_{in}$  is applied to a digital high-order all-pass filter  $j'$ . In this case, high-order all-pass filter  $j'$  provides a rapid rate-of-change of phase shift to a maximum of  $n(180)$  degrees, where  $n$  equals an odd integer greater than one, such that the total phase shift above substantially 200 Hz remains substantially 180-degrees. High-order all-pass filter  $j'$  provides as output an image enhanced left channel signal  $L_{out}$ . As will be apparent to one skilled in the art, high-order all-pass filter  $j'$ , in which maximum phase shift is limited to an odd multiple of 180-degrees and occurs over a narrow frequency region, may not be ordinarily implemented through an analog phase shifter or all-pass circuitry. Tight channel input signal  $R_{in}$  is applied to a time delay  $k'$ . Time delay  $k'$  introduces a constant time delay equal to the fixed delay introduced in the left channel and thereby provides as output an image enhanced right channel signal  $R_{out}$ .

A sixth alternative embodiment for the compensating phase shift component 14 of the present invention is shown in Figure 15. The left channel input signal  $L_{in}$  is applied to a first digital high-Q all-pass filter  $l'$ . In this embodiment, high-Q all-pass filter  $l'$  introduces a rapid rate-of-change of phase shift to a maximum first phase angle, thereby providing as output an image enhanced right channel signal  $R_{out}$ . Similarly, the right channel input signal  $R_{in}$  is applied to a second digital high-Q all-pass filter  $m'$  which introduces a rapid rate-of-change of phase shift to a maximum second phase angle, thereby providing as output an image enhanced right channel signal  $R_{out}$ . The maximum first phase angle and maximum second angle are selected to provide a maximum differential phase shift between the channels equal to substantially 180-degrees at substantially 200 Hz. To the extent necessary, the output from the high-Q all-pass filter  $m'$  (or alternatively from all-pass filter  $l'$ ) may optionally be processed by time delay  $n'$ . Time delay  $n'$  introduces a constant time delay equal to the fixed delay difference that may exist between the channels.

Lastly, a seventh alternative embodiment for the compensating phase shift component 14 of the present invention is shown in Figure 16. The left channel input signal  $L_{in}$  is applied to at least one conventional all-pass filter  $o'$  which provides a positive phase shift function. The output of conventional all-pass filter  $o'$  is applied to



at least one non-causal (time displaced) all-pass filter  $p'$ . The output of non-causal all-pass filter  $p'$  therefore combines positive phase shift and time displacement functions to provide a negative phase shift function  $q'$ . The negative phase shift function  $q'$  in turn provides as output an image enhanced left channel signal  $L_{out}$ . The right channel input signal  $R_{in}$  is applied to a time delay  $k'$ . Time delay  $k'$  introduces a constant time delay equal to the fixed delay introduced in the left channel and thereby provides as output an image enhanced right channel signal  $R_{out}$ . It is also envisioned that the conventional and non-causal all-pass filters may operate in opposing channels. When such filters operate in both channels, the constant delay may be eliminated or applied to either channel as may be required in specific applications. In any event, the conventional and non-causal all-pass filters are equivalent to the summed low-pass and high-pass filters, and thus introduce a rapid rate-of-change of phase shift to a maximum of substantially 180-degrees at substantially 200 Hz.

The foregoing discloses and describes merely exemplary embodiments of the present invention. One skilled in the art will readily recognize from such discussion, and from accompanying drawings and claims, that various changes, modifications, and variations can be made therein without departing from the spirit and scope of the present invention.



## CLAIMS

1. A digital signal processing system for symmetrical stereophonic image enhancement in an automotive listening environment, comprising:

input ports receiving stereo input signals from a stereo signal source;  
output ports providing left and right stereo output signals;

5 a digital signal process interconnected between the input ports and the output ports, the digital signal process having left and right signal paths and further includes

a phase shift component interposed into one of the left and right signal paths and operative to insert a rapid rate-of-change phase shift to a maximum of 180 degrees into the corresponding stereo signal; and

10 a time delay component interposed into the remaining signal path and operative to introduce a time delay into the corresponding stereo signal that is equal to the fixed time delay introduced by the phase shift component.

2. The digital signal processing system of Claim 1 wherein the phase shift component is operative to insert the rapid rate-of-change phase shift at substantially 200 Hertz.

3. The digital signal processing system of Claim 1 wherein the phase shift component is operative to insert the rapid rate-of-change phase shift at a frequency within the range of 150 to 300 Hertz.

4. The digital signal processing system of Claim 1 wherein the digital signal process further includes an adjustable clock, such that the frequency of the clock determines the frequency at which rapid rate-of-change phase shift occurs.



1990-1991		1991-1992		1992-1993		1993-1994		1994-1995		1995-1996		1996-1997		1997-1998		1998-1999		1999-2000		2000-2001		2001-2002		2002-2003		2003-2004		2004-2005		2005-2006		2006-2007		2007-2008		2008-2009		2009-2010		2010-2011		2011-2012		2012-2013		2013-2014		2014-2015		2015-2016		2016-2017		2017-2018		2018-2019		2019-2020		2020-2021		2021-2022		2022-2023		2023-2024		2024-2025		2025-2026		2026-2027		2027-2028		2028-2029		2029-2030		2030-2031		2031-2032		2032-2033		2033-2034		2034-2035		2035-2036		2036-2037		2037-2038		2038-2039		2039-2040		2040-2041		2041-2042		2042-2043		2043-2044		2044-2045		2045-2046		2046-2047		2047-2048		2048-2049		2049-2050		2050-2051		2051-2052		2052-2053		2053-2054		2054-2055		2055-2056		2056-2057		2057-2058		2058-2059		2059-2060		2060-2061		2061-2062		2062-2063		2063-2064		2064-2065		2065-2066		2066-2067		2067-2068		2068-2069		2069-2070		2070-2071		2071-2072		2072-2073		2073-2074		2074-2075		2075-2076		2076-2077		2077-2078		2078-2079		2079-2080		2080-2081		2081-2082		2082-2083		2083-2084		2084-2085		2085-2086		2086-2087		2087-2088		2088-2089		2089-2090		2090-2091		2091-2092		2092-2093		2093-2094		2094-2095		2095-2096		2096-2097		2097-2098		2098-2099		2099-2100		2100-2101		2101-2102		2102-2103		2103-2104		2104-2105		2105-2106		2106-2107		2107-2108		2108-2109		2109-2110		2110-2111		2111-2112		2112-2113		2113-2114		2114-2115		2115-2116		2116-2117		2117-2118		2118-2119		2119-2120		2120-2121		2121-2122		2122-2123		2123-2124		2124-2125		2125-2126		2126-2127		2127-2128		2128-2129		2129-2130		2130-2131		2131-2132		2132-2133		2133-2134		2134-2135		2135-2136		2136-2137		2137-2138		2138-2139		2139-2140		2140-2141		2141-2142		2142-2143		2143-2144		2144-2145		2145-2146		2146-2147		2147-2148		2148-2149		2149-2150		2150-2151		2151-2152		2152-2153		2153-2154		2154-2155		2155-2156		2156-2157		2157-2158		2158-2159		2159-2160		2160-2161		2161-2162		2162-2163		2163-2164		2164-2165		2165-2166		2166-2167		2167-2168		2168-2169		2169-2170		2170-2171		2171-2172		2172-2173		2173-2174		2174-2175		2175-2176		2176-2177		2177-2178		2178-2179		2179-2180		2180-2181		2181-2182		2182-2183		2183-2184		2184-2185		2185-2186		2186-2187		2187-2188		2188-2189		2189-2190		2190-2191		2191-2192		2192-2193		2193-2194		2194-2195		2195-2196		2196-2197		2197-2198		2198-2199		2199-2200		2200-2201		2201-2202		2202-2203		2203-2204		2204-2205		2205-2206		2206-2207		2207-2208		2208-2209		2209-2210		2210-2211		2211-2212		2212-2213		2213-2214		2214-2215		2215-2216		2216-2217	
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5



FIG. 1.

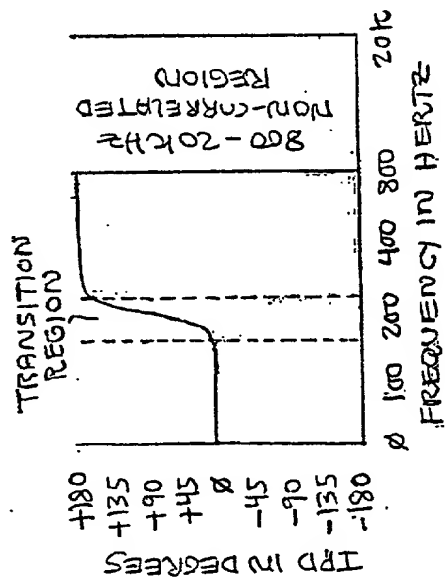


FIG. 2.

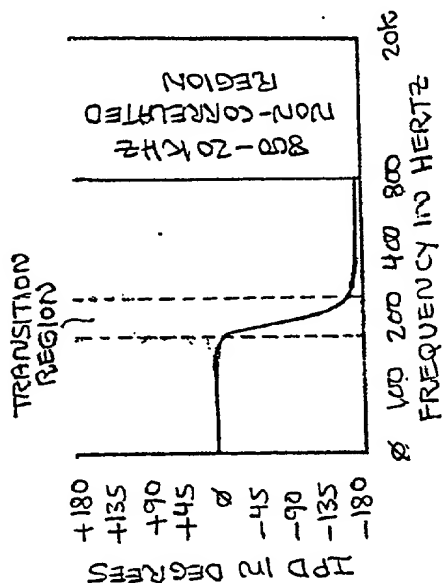


FIG. 3.

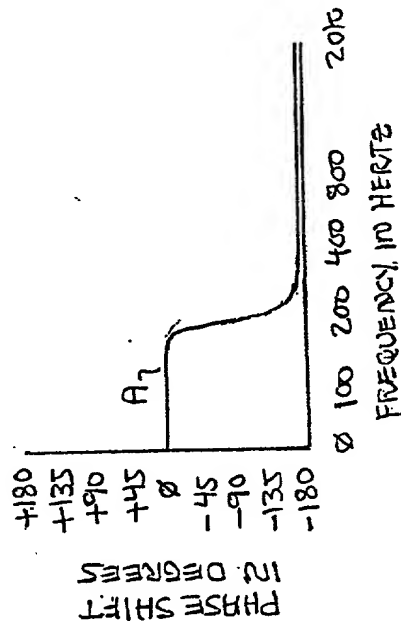


FIG. 4.

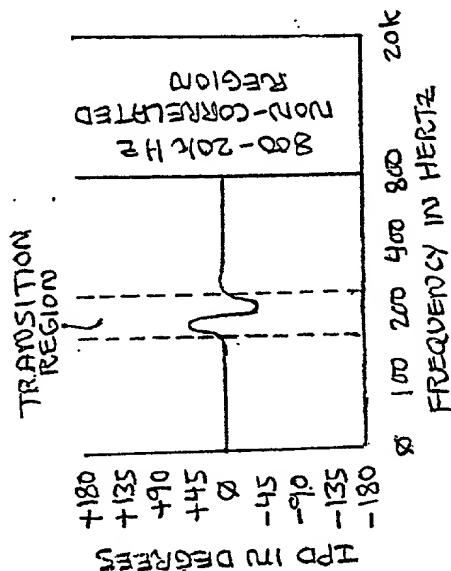




FIG. 5.

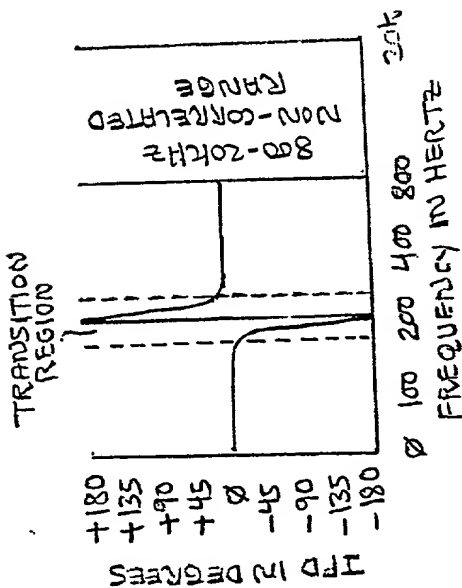


FIG. 6.

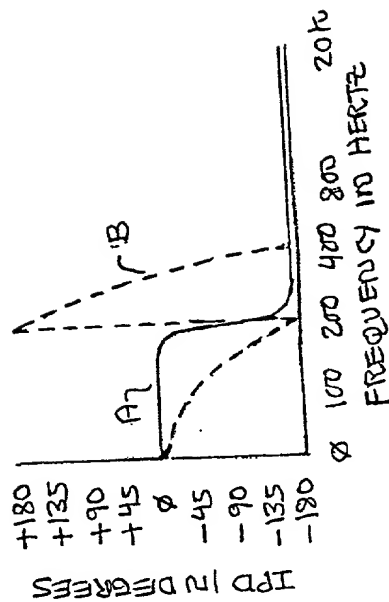


FIG. 7.

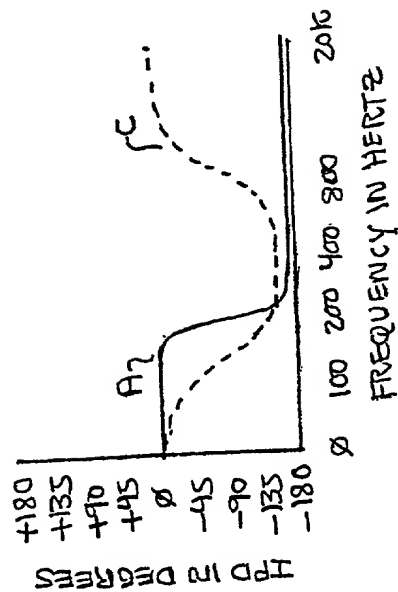


FIG. 8.

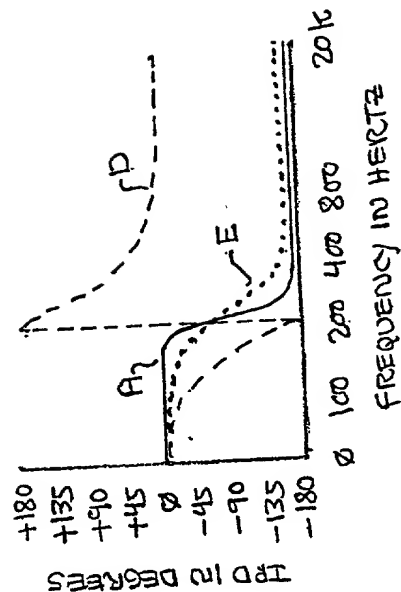








FIG. 11

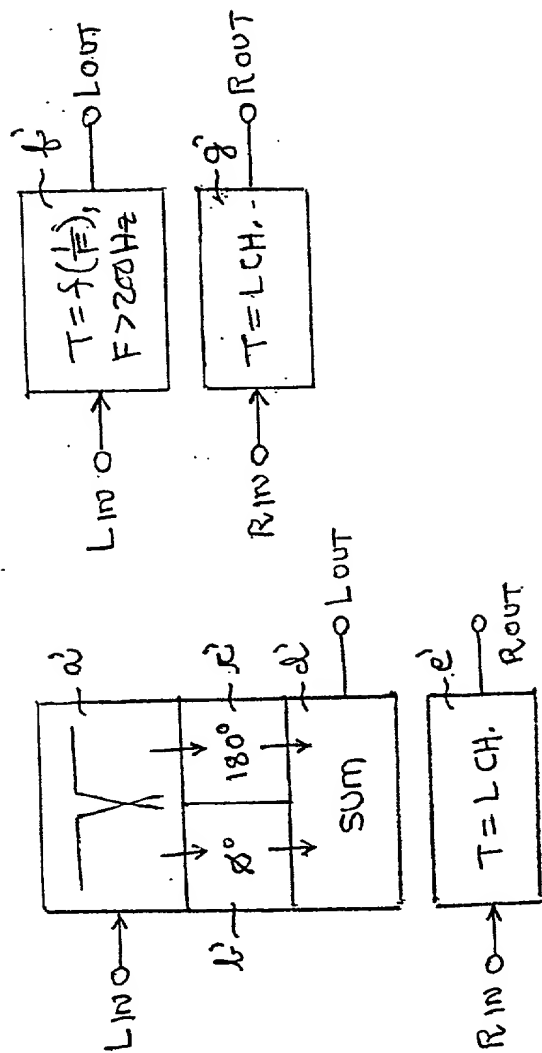


FIG. 12

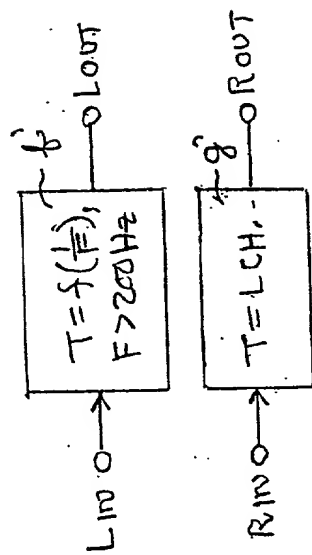


FIG. 13

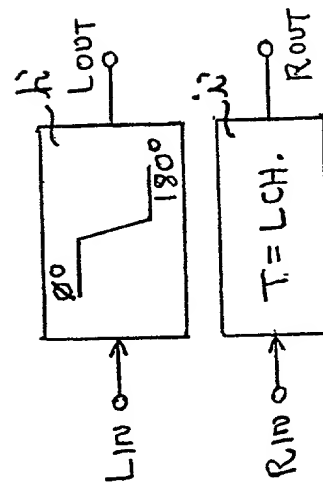
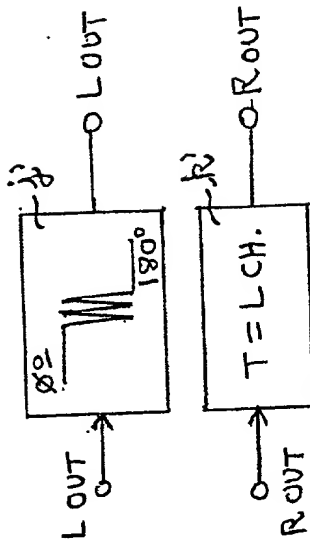


FIG. 14









## DECLARATION AND POWER OF ATTORNEY

As below named inventors, we hereby declare that:

Our residences, post office addresses and citizenships are as stated below next to our names,

We believe we are the original, first and joint inventors of the subject matter which is claimed and for which a patent is sought on the invention entitled

### DIGITAL SIGNAL PROCESSING FOR SYMMETRICAL STEREOPHONIC IMAGING IN AUTOMOBILES

the specification of which (check one)

☒ [ X ] is attached hereto.

☐ [ ] was filed on \_\_\_\_\_ as Application  
Serial No. \_\_\_\_\_ and was amended on  
\_\_\_\_\_ (if applicable).

We hereby state that we have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

We acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, section 1.56.

We hereby claim foreign priority benefits under Title 35, United States Code, section 119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

#### PRIOR FOREIGN APPLICATION(S)

			<u>Priority Claim</u>	
(Number)	(Country)	(Day/Month/Year filed)	Yes	No
_____	_____	_____	_____	_____
(Number)	(Country)	(Day/Month/Year filed)	Yes	No
_____	_____	_____	_____	_____
(Number)	(Country)	(Day/Month/Year filed)	Yes	No
_____	_____	_____	_____	_____



## DECLARATION AND POWER OF ATTORNEY

We hereby claim the benefit under Title 35, United States Code, §119(e) of any United States Provisional application(s) listed below:

### PRIOR PROVISIONAL APPLICATIONS

<u>60/179,254</u> (application serial number)	<u>January 31, 2000</u> (Month / Day / Year filed)
<u>60/163,221</u> (application serial number)	<u>November 2, 1999</u> (Month / Day / Year filed)
<u>60/162,044</u> application serial number)	<u>October 26, 1999</u> (Month / Day / Year filed)
<u>60/161,276</u> application serial number)	<u>October 25, 1999</u> (Month / Day / Year filed)

We hereby claim the benefit under Title 35, United States Code, section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, section 112, we acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, section 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

Application Serial No.	Filing Date	Status - patented, pending, abandoned
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

We hereby appoint DAVID P. UTYKANSKI, Reg. No. 39,052 and TIMOTHY D. MACINTYRE, Reg. No. 42,842, and each principal, attorney of counsel, associate and employee of Harness, Dickey & Pierce, P.L.C., who is a registered Patent Attorney, our attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith. We request the Patent and Trademark Office to direct all correspondence and telephone calls relative to this application to Harness, Dickey & Pierce, P.L.C., P. O. Box 828, Bloomfield Hills, Michigan 48303 (248) 641-1600.



[illegible]

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Inventor's signature: \_\_\_\_\_

Date: \_\_\_\_\_

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Citizenship: USA

Post Office Address: \_\_\_\_\_